Examining Sustained Attention in Child-Parent Interaction: A Comparative Study of Typically Developing Children and Children with Autism Spectrum Disorder

Julia R. Yurkovic[1], Grace Lisandrelli[1], Rebecca C. Shaffer[2,4], Kelli C. Dominick[3,4], Ernest V. Pedapati[3,4], Craig A. Erickson[3,4], Daniel P. Kennedy[1+], and Chen Yu[1+]

[1] Indiana University, Department of Psychological and Brain Sciences, Bloomington, IN, 47401, USA
[2] Cincinnati Children's Hospital, Department of Pediatrics, Cincinnati, OH 45229, USA
[3] Cincinnati Children's Hospital, Department of Psychiatry and Behavioral Neuroscience, Cincinnati, OH 45229, USA
[4] University of Cincinnati, School of Medicine, Cincinnati, OH 45229, USA
[+] These authors contributed equally to this work

Abstract

Sustained attention (SA) is a critical skill in which a child is able to maintain visual attention to an object or stimulus. The current study employs head-mounted eye trackers to study the cognitive processes underlying SA by analyzing micro-level behaviors during parent-child social interactions in both typically and atypically developing children. Specifically, we examined the role of parent look, parent touch, and child touch on SA duration. Results show that parent look equally influences SA in both groups, while parent touch is more critical for SA for TD children and the child's own touching is more critical for SA in children with autism spectrum disorder (ASD). Implications of different pathways to maintain SA between typically developing children and children with ASD are discussed.

Keywords: micro-level behaviors; eye tracking; sustained attention; action; social attention; autism spectrum disorder

Introduction

Sustained attention (SA) is the ability to maintain attention to an object or stimulus for an extended amount of time and reflects an increased ability to withstand distraction. SA develops throughout infancy and early childhood (Kannass et al., 2006; Ruff & Capozzoli, 2003; Ruff & Lawson, 1990) and has been linked to language (Yu et al., 2019) and cognitive development (Bakeman & Adamson, 1984; Johansson et al., 2015). SA has typically been studied in constrained laboratory tasks and generally performed in isolation as it is classically viewed as an endogenous visual attentional ability of the child (Mundy & Newell, 2007).

Recent advancements have allowed researchers to use head-mounted eye trackers to study children in naturalistic, social environments and to analyze micro-level behaviors as they unfold moment-by-moment, thereby revealing cognitive processes on short timescales. This line of research has broadened our understanding of the cognitive mechanisms underlying SA in typically developing (TD) children to include social attention and manual activity. Two studies found that a child's SA during toy play was extended when a parent looked to the same toy at the same time (Yu & Smith, 2016) and was further extended by parent talk or touch (Suarez-Rivera et al., 2019). Additional research suggests that the child's actions during play are important for constraining their visual attention. When children play with toys, they often coordinate their gaze with what is in their hands (Yu & Smith, 2017a, 2017b), allowing the child to constrain his or her attention (Bambach et al., 2017). These moments where a child looks to a toy in their hands have been identified as important for object name learning (Slone et al., 2019; Yu & Smith, 2017a, 2017b), but may also be important for the development of attentional skills.

If social attention and manual action are important factors for the development of SA, one group that may be impacted is children with autism spectrum disorder (ASD). ASD is a disorder characterized by deficits in social attention and interaction, but individuals with the disorder also display deficits in attention and action (Ozonoff et al., 2008). Abnormalities in social attention and abilities are evidenced across the lifespan in individuals with ASD (Klin et al., 2002; Pierce et al., 2016), which could lead to children with ASD having less access to important attention skill-building and learning moments. Furthermore, past research reports that children with ASD generate atypical actions on toys (Ozonoff et al., 2008; Zwaigenbaum et al., 2005). These atypical motor behaviors may relate to an atypical development of hand-eye coordination and other attentional skills, including SA.

Despite reported differences between children with ASD and TD children in social attention and visual-manual coordination, some studies of children with ASD have found no core deficit in SA (Johnson et al., 2007; Pascualvaca et al., 1998). Still, the equivalent performance of children with ASD and TD children on SA tasks may arise through the support of different cognitive processes that may cause atypical patterns of behavior in other tasks. Without a deeper understanding of the processes supporting SA, it is premature to claim intactness of internal attentional processes.

Current Study

Taken together, the current study aims to examine the micro-level behaviors underlying SA in early development and to identify potential similarities and differences across TD children and children with ASD. The results will shed light on differing developmental processes, including if and to what degree social attention and manual action relate to SA, and if any of these factors are more critical than others for the extension of SA. Specifically, we aim to answer: (1) If children with ASD sustain their attention at a similar rate to their TD peers; (2) if and how the visual attention and manual action of a social partner (the parent in the present study), relate to the presence and duration of child SA; and (3) if and how a child's coordination of attention with their own manual action relates to the presence and duration of SA.

To answer these questions, we first examined the rate at which children generated SA looks and the duration of these looks. If children with ASD show less SA overall, it may be reflective of an attention deficit. If, however, children with ASD show similar rates of SA, it would suggest an intact ability to maintain attentional focus.

Next, we investigated the role of the parent on the child's SA. Specifically, we investigated parent looking and touching behaviors to further understand the social influences on children's attentional abilities. A difference between groups would suggest a difference in social cueing or responsiveness and a difference in the way behaviors are used to support child SA. A similarity would reflect that dyads in both groups use similar strategies to extend child SA.

Finally, we assessed the role of a child's own manual actions on their SA. We investigated the rate at which children touched toys during SA and if touching related to an extension of SA. Differences in the coordination of manual action with SA between groups would be reflective of different attentional strategies during play. A similarity would reflect that children in both groups use manual action to support their attention in similar ways.

Methods

Participants

We collected usable eye tracking data from 17 TD dyads and 19 ASD dyads. Data collection for the TD dyads was conducted at Indiana University, and data collection for ASD dyads was conducted at Cincinnati Children's Hospital. The two locations used the same testing equipment, stimuli, procedures, and personnel. All ASD diagnoses were confirmed according to the DSM-V criteria by a trained clinician. Table 1 provides characterization information for the ASD and TD children. The two groups did not differ on age, $t(29)<0.01$, $p=0.99$ or sex distribution, $\chi 2$ $(N=29)=0.72$, $p=0.40$. As a group, children with ASD were extremely delayed in expressive and receptive language (Table 1).

Table 1: Participant Characterization

	TD n=17	ASD n=19
Age (Months)	36.2 (7.8)	36.3 (7.2)
Sex (M/F)	13 / 4	13 / 6
Mullen Receptive Language AE	11.5 (5.5)	---
Mullen Expressive Language AE	13.4 (6.8)	---

* Mullen = Mullen Scales of Early Learning
* AE = Age Equivalent (Months)

Procedure and Stimuli

Parents and their children were brought into a room that resembled a playroom. Dyads were seated on a carpet together, typically at a 90° from each other or with the child seated on the parent's lap. Each dyad member was equipped with a head-mounted eye tracker and scene camera affixed to either a pair of glasses (parent) or a hat (child). For each dyad member, the experimenter would first modify the position of the eye camera to capture eye movement and then adjust the angle of the scene camera to capture the scene directly in front of the participant. The scene camera was adjusted so that the hands were visible in the participant's own lap to ensure that all manual actions were captured. After eye tracker setup, the dyads were given a set of 24 everyday toys that were spread on the carpet. Parents were instructed to play with their child as they would at home with no explicit instruction about how to interact with the toys or one another.

Data Processing

Videos were recorded from parent and child eye and scene cameras, as well as several cameras around the play space. Parent and child eye-tracking videos were calibrated off-line to overlay a cross-hair representing eye movements onto the video of the participant's scene camera. Following the calibration procedure, gaze coding was conducted by trained human coders for each participant. A custom program was used to divide the continuous gaze data into individual looks based on the velocity of the eye movements. Coders then identified if the crosshair was located on one of the 24 toys

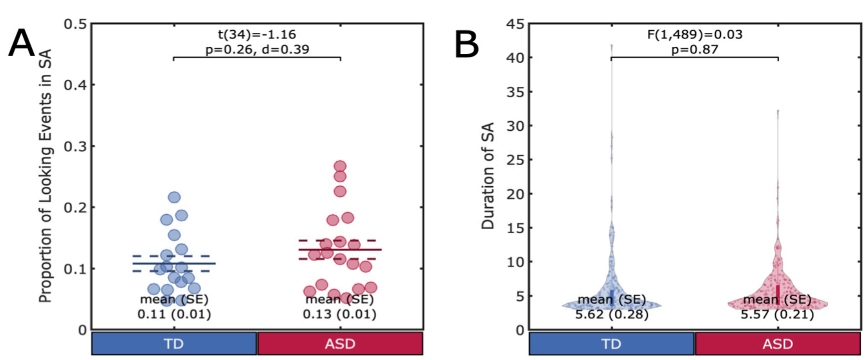

Figure 1: (A) Each dot represents an individual child. The mean is represented by a solid line and the standard error by a dotted line. Groups generated similar proportions of SA looks. (B) Violin plots represent the probability density of the duration of SA for each group. Box plots are overlaid to display the first quartile through third quartile for each group. There was no difference between groups in overall SA duration.

or on the other dyad member's face for each look. Following gaze coding, SA moments were defined as any look that was greater than or equal to 3 seconds long, following standards in the field (Suarez-Rivera et al., 2019; Yu & Smith, 2016).

Manual action was coded frame-by-frame using the scene camera and the other camera views from the play space. Trained coders first identified all manual action of the right hand and then repeated the process for all actions of the left hand for both dyad members. A manual action was coded as soon as the participant's hand came in contact with an object. During data analysis, manual action events were merged if both hands were touching the same toy simultaneously.

Results

SA Rates and Duration

We first examined if TD children and children with ASD are sustaining their attention to toys at a similar rate during play. We first computed the proportion of looking events that resulted in SA (looks ≥ 3s) by dividing the number of SA looks by the total number of looks to toys. TD children and children with ASD generated SA looks at a similar rate on average across the session (TD: 11% (SE±1%); ASD: 13% (2%); $t(34)=-1.16$, $p=0.26$, $d=0.39$) (see Figure1a).

Next, we determined if the duration of SA is similar between groups. For this analysis, we created a corpus of all SA moments for all participants in each group. The corpus was used for all further analyses. The overall SA duration was 5.60s (0.17s), and the two groups produced similar SA durations (TD: 5.62s (0.28s); ASD: 5.57s (0.21s)). We ran a linear mixed effects (LME) model on SA duration with fixed effects for group and random effects for participant to account for the variability in SA duration for each participant. An analysis of variance (ANOVA) on the LME model revealed no difference between groups, $F(1,489)=0.03$, $p=0.87$. Overall, the time TD children and children with ASD spent in SA arose from similar dynamics of looks generated and the duration of these SA looks during toy play.

Parent Look

Recent work has shown that a child's SA is extended when parents attend to the same object at the same time (Suarez-Rivera et al., 2019; Yu & Smith, 2016). In light of those findings, we next examined how parent looking relates to SA in children with and without ASD.

We first calculated the proportion of each instance of SA where the parent looked to the same toy as the child, thereby creating a moment of joint attention. On average, parents in both groups did not differ on the proportion of their child's SA that they looked to the target toy (TD: 44% (2%); ASD: 41% (2%)). An ANOVA on an LME examining the proportion of child SA that overlapped with a parent look, with fixed effects of group and random effects for participant, revealed no difference between groups, $F(1,530)=0.50$, $p=0.48$ (see Figure 2a). This suggests that shared visual attention with a parent on an object may play a similar role in supporting child SA in both groups.

Next, we compared the durations of SA instances that either did or did not co-occur with parent look for each group

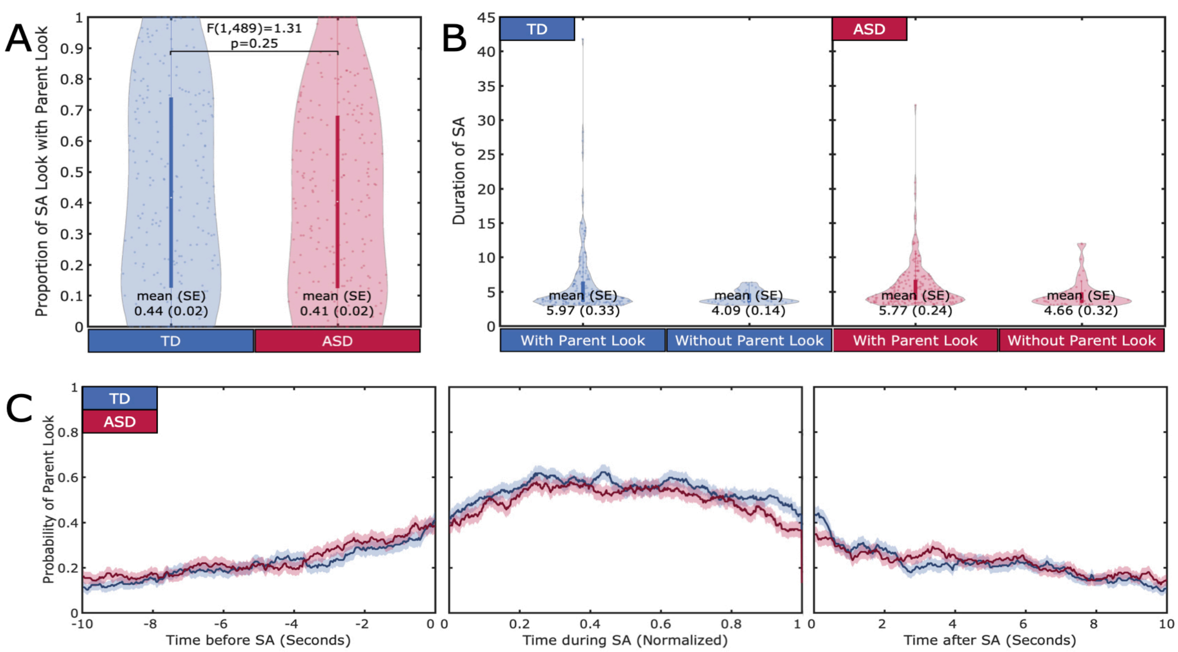

Figure 2: Violin plots in (A-B) represent the probability density of the measure for each group. Box plots are overlaid to display the first through third quartile for each group. (A) Parents of children with ASD look at toys for a similar proportion of SA compared to TD peers. (B) SA moments without parent look are shorter overall, but there is no difference between groups or in the interaction between group and SA type. (C) Considering only the instances of SA with parent look, the probability of parent look increases in the 10s before SA, peaks about halfway through SA, and decreases in the 10s following SA. There are no differences in the temporal dynamics between groups.

(see Figure 2b). We conducted an LME with fixed effects for group and SA type (with or without parent look) and random effects for participant. As previously observed, there is no main effect of group on SA duration. We observed a main effect of SA type, $F(1,487)=11.33$, $p<0.01$, indicating that SA events with parent looking were 1.50s longer on average (5.87s (0.21s)) than SA events without parent looking (4.37s (0.18s)). The interaction effect was non-significant, $F(1,487)=0.75$, $p=0.39$, suggesting that parent look relates to the extension of SA in a similar manner across groups. This also suggests that children with ASD are equally sensitive to the attention of a social partner during play as their TD peers.

We next explored the temporal dynamics of parent looking behavior surrounding and during child SA (see Figure 2c). In the instances where parents did visually attend, the likelihood that a parent in either group looked to the toy steadily increased by 31% for TD children and 25% for children with ASD in the 10s preceding SA. Both groups follow their parent's gaze into SA about 40% of the time, further suggesting that TD children and children with ASD are sensitive to their parent's gaze. The probability of parent visual attention peaked halfway through the child's SA at 62% and 58% for TD children and children with ASD, respectively. This further suggests that parents are responding to their child's gaze between groups at equal rates. Finally, the probability of parent looking progressively decreased in the 10s after SA by 35% for the TD children and 22% for the children with ASD. The groups do not show a different average temporal pattern of parent visual attention.

Overall, we saw no difference between TD children and children with ASD on the proportion or duration of SA with parent look, and no difference in the temporal dynamics of coordinating parent look with child SA. Parents in both groups looked to the same toy as the child at a similar rate with similar dynamics, and the presence of parent look during SA related to a boost in SA duration for both groups.

Parent Touch

Parents use multimodal behaviors when playing with their children (Yu & Smith, 2012, 2013), and parent touch has been identified as one behavior that may support a child's attention to an object, with children often shifting their attention to attend to an object that a parent is manipulating (Deák et al., 2014; Yu & Smith, 2017a). Therefore, we next examined the role of parent manual action on child SA.

First, we calculated the proportion of each SA instance where the parent was touching the toy. Parents of TD children touched the target toy during a child's SA for 11% more on average than parents of children with ASD (TD: 29% (2%); ASD: 18% (2%)). An ANOVA on an LME examining the proportion of SA with parent touch overlap with fixed effects for group and random effects for participant revealed a difference between groups, $F(1,489)=12.86$, $p<0.01$ (see Figure 3a). Parents of TD children touched the toy for significantly longer than parents of children with ASD, suggesting that parent touch may be more related to SA among TD children than among children with ASD.

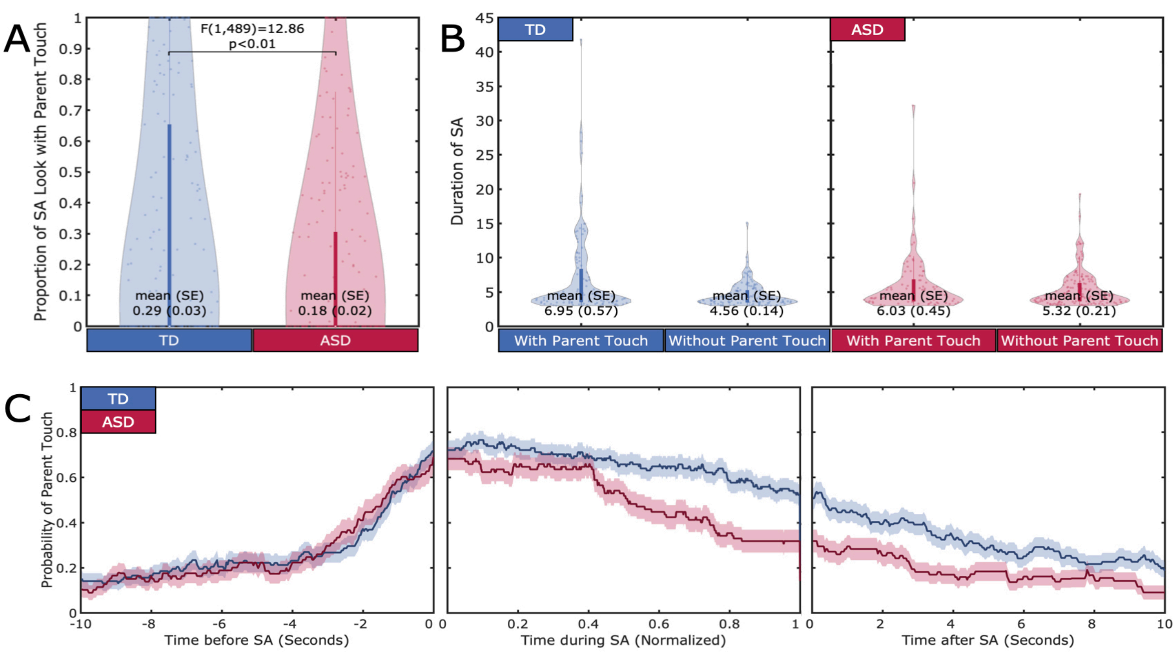

Figure 3: Violin plots in (A-B) represent the probability density of the measure for each group. Box plots are overlaid to display the first through third quartile for each group. (A) Parents of TD children touch toys more during SA than parents of children with ASD. (B) SA moments without parent touch are shorter overall. There is a significantly greater increase in SA duration with parent touch in the TD group relative to the ASD group. (C) Considering only the instances of SA where the parent touched the target toy, the probability of parent touch increases in the 10s before SA, with the biggest increase being from 4s before to the onset of SA. The probability of parent touch decreases throughout SA at different rates for the two groups and continues to decrease after SA.

Next, we compared the duration of SA instances that either did or did not co-occur with parent touch for each group (see Figure 3b). We conducted an LME with fixed effects for group and SA type (with or without parent touch). As previously observed, there is no main effect of group on SA duration. We observed a main effect of SA type, $F(1,487)=19.91$, $p<0.01$, indicating that SA events with parent touching were 1.59s longer on average (6.55s (0.38s)) than SA events without parent touching (4.96s (0.13s)). The interaction effect was significant, $F(1,487)=5.80$, $p=0.02$. Post-hoc Tukey tests revealed that SA duration increased significantly with parent touch compared to that without parent touch for TD children, $t(248)=4.45$, $p<0.01$, $d=0.57$, but not for children with ASD, $t(239)=1.64$, $p=0.10$, $d=0.39$. This suggests that TD children are better able to coordinate their attention with objects in their parent's hands than children with ASD.

We next explored the temporal dynamics of parent touching behavior surrounding and during child SA (see Figure 3c). In the instances where parents touched the toy during SA, the likelihood that a parent touched the toy increased in the 10s preceding SA by 59% for TD children and by 60% for children with ASD, with a steep increase in probability around 4s before child SA. For both groups, parent touch typically preceded SA, suggesting that children in both groups were attuned to the actions of their parent. The probability of parent touch decreased during child SA for both groups, but the probability decreased by 14% less for TD children than for children with ASD. The likelihood of parent touch remained slightly elevated for TD children compared to children with ASD in the 10s following SA. This suggests that parent touch supports TD children's SA, but that a decrease in parent touch may provide children with ASD the opportunity to maintain SA.

Overall, we observed that the use of touching by parents differentially related to SA between TD and ASD dyads. Parents of TD children touch more frequently, and the increase in SA with parent touch compared to without parent touch is greater for TD children than for children with ASD.

Child Touch

Children generate actions on toys during play to select objects of interest, thereby influencing their own visual attention (Yu et al., 2009). The ability to manually act on toys relates to and supports visual SA in TD toddlers (Yuan et al., 2019). Our recent research suggests that manual action and visual-manual coordination during naturalistic toy play does not differ between children with ASD and their TD peers (Yurkovic et al., Under Review). However, it remains an open question whether and how hand-eye coordination during play might differentially relate to higher-order cognitive processes such as SA in children with ASD compared to their TD peers.

We first determined how often children are acting upon objects during SA. We computed the proportion of each SA instance where the child was touching the toy. TD children on average touched the target toy for 7% less than children with ASD during SA. (TD: 65% (3%); ASD: 72% (2%)). We ran an LME on the proportion of SA with child touch overlap with fixed effects for group and random effects for

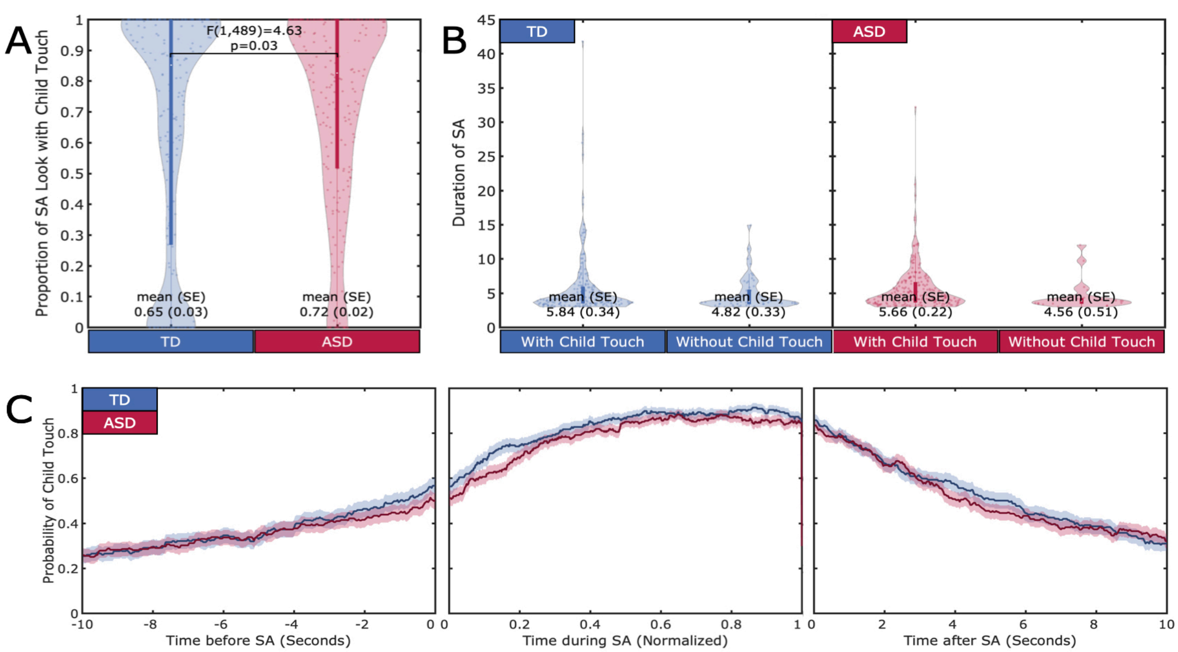

Figure 4: Violin plots in (A-B) represent the probability density of the measure for each group. Box plots are overlaid to display the first through third quartile for each group. (A) children with ASD touch more during SA than their TD peers. (B) SA moments without child touch are shorter overall. There is no difference between groups in the boost of SA duration with child touch compared to without child touch. (C) Considering only the instances of SA with child touch, the probability of child touch increased in the 10s before SA and during SA. The probability of child touch decreased following SA. There are no differences in the temporal dynamics between groups.

participant. An ANOVA on the LME revealed a difference between groups, F(1,489)=4.63, p=0.03 (see Figure 4a). Child manual activity may play a larger role in maintaining SA for children with ASD than for TD children.

Next, we compared the durations of SA instances that either did or did not co-occur with child touch for each group (see Figure 4b). We conducted an LME with fixed effects for group and SA type (with or without parent touch). As previously observed, there is no main effect of group on SA duration. We observed a main effect of SA type, F(1,487)=3.89, p=0.05, indicating that SA instances with child touch were longer (6.17s (0.20s)) than those without child touch (4.88s (0.30s)). The interaction effect was not significant, F(1,487)=0.01, p=0.94, suggesting that SA duration in both groups was extended by child touch.

We next explored the temporal dynamics of child touch surrounding and during child SA (see Figure 4c). In the instances where children touched the toy during SA, the likelihood that the child touched the toy increased by 31% and 26% for TD children and children with ASD, respectively, in the 10s preceding SA. In both groups, the probability of child touch increased during child SA, peaking at 91% probable for TD children and 88% probable for children with ASD in the second half of the SA instances. This increase most likely coincides with the decrease in probability of parent touch during SA. The probability of child touch decreased by 55% TD children and 52% for children with ASD in the 10s after SA, suggesting that manual activity on toys is tightly linked to visual attention. There were no differences in the temporal dynamics of child touch, suggesting that the role of child hand-eye coordination on SA is similar for the two groups.

Overall, children with ASD manually act on objects during SA more than their TD peers. Child touch during SA related to a similar boost in SA duration between groups, suggesting that children with ASD require more hand-eye coordination to achieve a similar duration of SA as their TD peers. There were no differences in the temporal dynamics of child touch for the SA instances that did coincide with touch.

Discussion

The current study used head-mounted eye tracking to quantify how child and parent behaviors during dyadic play might support SA in children with and without ASD. We first determined if children with ASD sustain their attention to toys at a similar rate to their TD peers. Our results suggest that children with ASD have an intact ability to sustain attention to toys during play, a result that is consistent with past work showing no differences between groups (Johnson et al., 2007; Pascualvaca et al., 1998). SA looks in the two groups were generated at a similar rate and had a similar average duration, suggesting that children with ASD are achieving typical levels of focused attention during play. We next quantified the role of additional parent and child behaviors on the child's SA. Parent look to toys played a similar role between groups. The parent's manual actions may play a larger role in SA for TD children than for children with ASD, while children with ASD may rely more on their own hand-eye coordination to achieve SA. This may represent an internal, rather than social, locus of attention distribution for children with ASD.

Past research exploring the role of the social partner in a child's SA found that the parent's visual attention to the same toy at the same time related to an extension of SA (Suarez-Rivera et al., 2019; Yu & Smith, 2016). Our result supports this finding, showing that the duration of SA increased with the presence of parent look in both groups. We saw no difference between groups in the proportion of time that parents looked to the target of SA. In line with past literature, we found that parents of children with ASD are equally responsive to their children's attention (Van Ijzendoorn et al., 2007). We found that children with ASD are equally responsive to the visual attentional cues of their parent, which merits further exploration.

Children attend to objects that their parent is manually acting upon (Deák et al., 2014; Yu & Smith, 2017a), so we next examined the role of parent touching behavior on child SA. We found differences in the role of parent manual action between groups. Relative to parents of TD children, parents of children with ASD touched toys less frequently overall during SA, and the children with ASD had less of an extension in SA duration with parent touch compared to without parent touch. Dyads develop interaction styles over time (Bornstein & Tamis-LeMonda, 1990), and it is likely that these differences represent differences in strategy that the parents in both groups have learned for supporting their children during play. children with ASD may be more likely to look at objects in their own hands than at objects in the parent's hands, while TD children may redirect their attention to toys in their parents' hands more readily. Additionally, parents of children with ASD may be more selective in using manual action as a behavioral cue relative to parents of TD children.

Finally, we explored the role of the children's own behavior on their SA. children with ASD generate more actions to toys during SA than their TD peers. Our past research found no differences in the rate of manual action or visual-manual coordination in children with ASD relative to TD peers during naturalistic play (Yurkovic et al., Under Review). However, it is possible that visual-manual coordination differentially supports cognitive processes such as SA, despite similar levels of coordination throughout play.

Taken together, our results present promising findings for the study of cognitive processes during naturalistic dyadic interactions. We found that intact SA abilities in children with ASD may be supported through different behavioral cues than those employed by their TD peers. Understanding the mechanisms that children and parents use to coordinate their attention during play to support higher-level cognitive processes may provide an inroad to targeted early interventions for ASD, as well as key insights into the development of social and attentional deficits in ASD. Future research will quantify the dynamics between the behaviors that support a child's focused visual attention and to explore the mechanisms for maintaining attention to a toy once in SA.

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